ARKIV FÖR FYSIK Band 13 nr 7

Communicated 11 September 1957 by E. HULTHÉN

Health hazards from fission products and fallout

I. Products of instantaneous fission of U^{235} with thermal neutrons

By KERSTIN LÖW and ROLF BJÖRNERSTEDT

With 4 figures in the text

Radioactive fallout from atomic weapons may in several ways give rise to health hazards, either the fallout is used as a weapons effect in atomic warfare or is produced undesirably in the testing of weapons. External irradiation of human beings and uptake of radioactivity in the biosphere with subsequent internal irradiation are the two most important hazards. An evaluation of these and related effects must be based on a knowledge of the composition and decay properties of the fallout. Different kinds of atomic weapons however give different kinds of fallout. The detonation procedure may likewise introduce irregularities in the fallout composition. Selective processes may play an important role during the condensation of the radioactive particles and during their transport in the atmosphere.

Fission products constitute the major part of the fallout. Their composition is in the case of atomic bombs given from yield values for fission of U^{235} and Pu^{239} with neutrons having an energy distribution around 1 Mev, as given e.g. by Hughes [1]. In hydrogen bombs on the other hand the fission products originate from the natural uranium tamper as a result both of fission neutrons and 14 Mev thermonuclear neutrons.

It is apparent that a full account of the possible composition of fallout would imply an investigation of many fission product mixtures. The present knowledge of fission yield values is far from complete against this background. The best values are those for slow neutron fission of U^{235} [2–8], Pu^{239} [9, 10] and U^{233} [11, 12]. Less reliable data are found for fast neutron fission [13–15]. It can in general be said that the yield data around the two mass peaks vary less than a factor of two between different slow neutron fissioning nuclides. To both sides of the mass peaks there are greater variations which however have less influence on the total fission product mixture. Another general feature is that an increase in neutron energy increases the tendency for symmetric fission giving higher yield values in the mass valley. For 14 Mev neutrons this increase is about a hundred times over the values for thermal fission.

The calculation of the composition of fission product mixtures is simple in principle but tedious in practice as about 150 different isotopes have to be considered. When the mixture resulting from one fission mode is known, however, other mixtures (i.e. from other nuclides and neutron energies) are more easily calculated relative to the first one. For this reason and considering known yield values, U^{235} has been chosen as the best object of accurate calculation. Results for other nuclides will be published later. It should furthermore be pointed out that the ultimate purpose for which

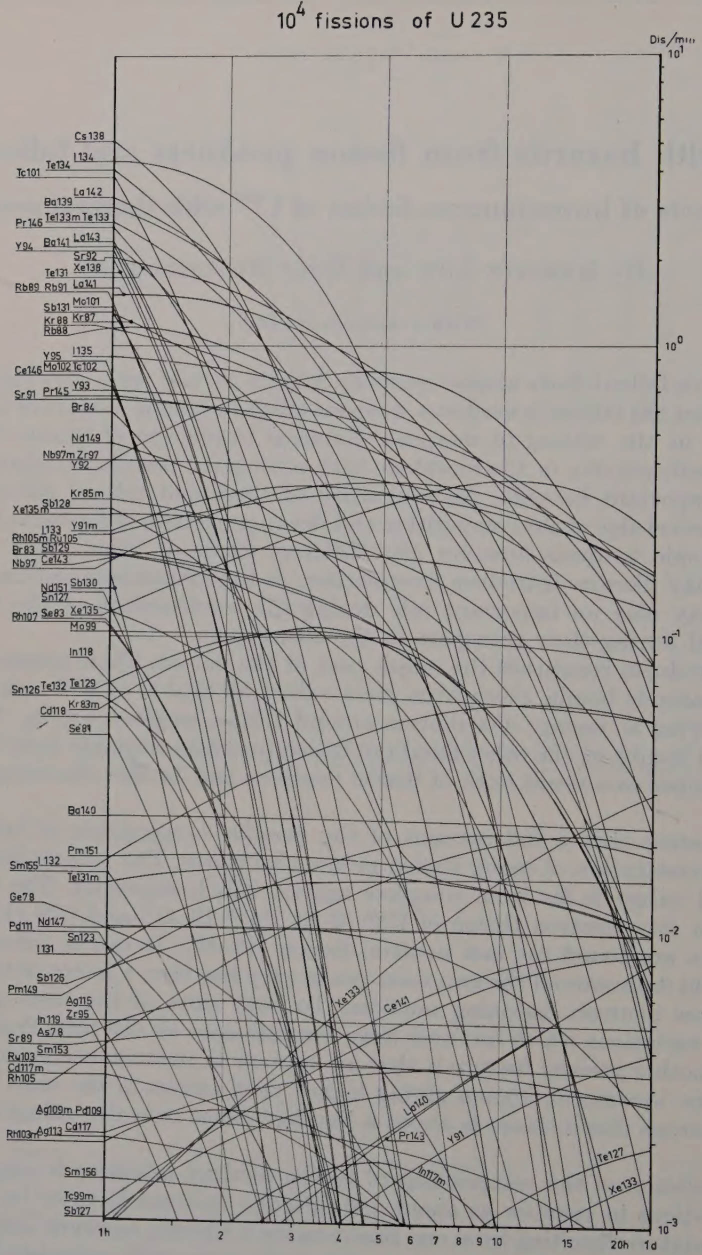
10^4 fissions of U 235
Dis/min
10^1
10^0
10^-1
10^-2
10^-3
Cs138
I134
Te134
Tc101
La142
Ba139
Pr146
Te133m Te133
Y94
Ba141
La143
Sr92
Te131
Xe138
Rb89
Rb91
La141
Sb131
Mo101
Kr88
Kr87
Rb88
Y95
I135
Ce146
Mo102
Tc102
Sr91
Pr145
Y93
Br84
Nd149
Nb97m
Zr97
Y92
Kr85m
Xe135m
Sb128
I133
Y91m
Rh105m
Ru105
Br83
Sb129
Nb97
Ce143
Nd151
Sb130
Sn127
Rh107
Se83
Xe135
Mo99
In118
Sn126
Te132
Te129
Cd118
Kr83m
Se81
Ba140
Sm155
I132
Pm151
Te131m
Ge78
Pd111
Nd147
Sn123
I131
Sb126
Pm149
Ag115
In119
Zr95
Sr89
As78
Ru103
Sm153
Cd117m
Rh105
Ag109m
Pd109
Rh103m
Ag113
Cd117
Sm156
Tc99m
Sb127
Xe133
Ce141
La140
Pr143
Y91
In117m
Te127
Xe133
1h
2
3
4
5
6
7
8
9
10
15
20h
1d

Fig. 1.

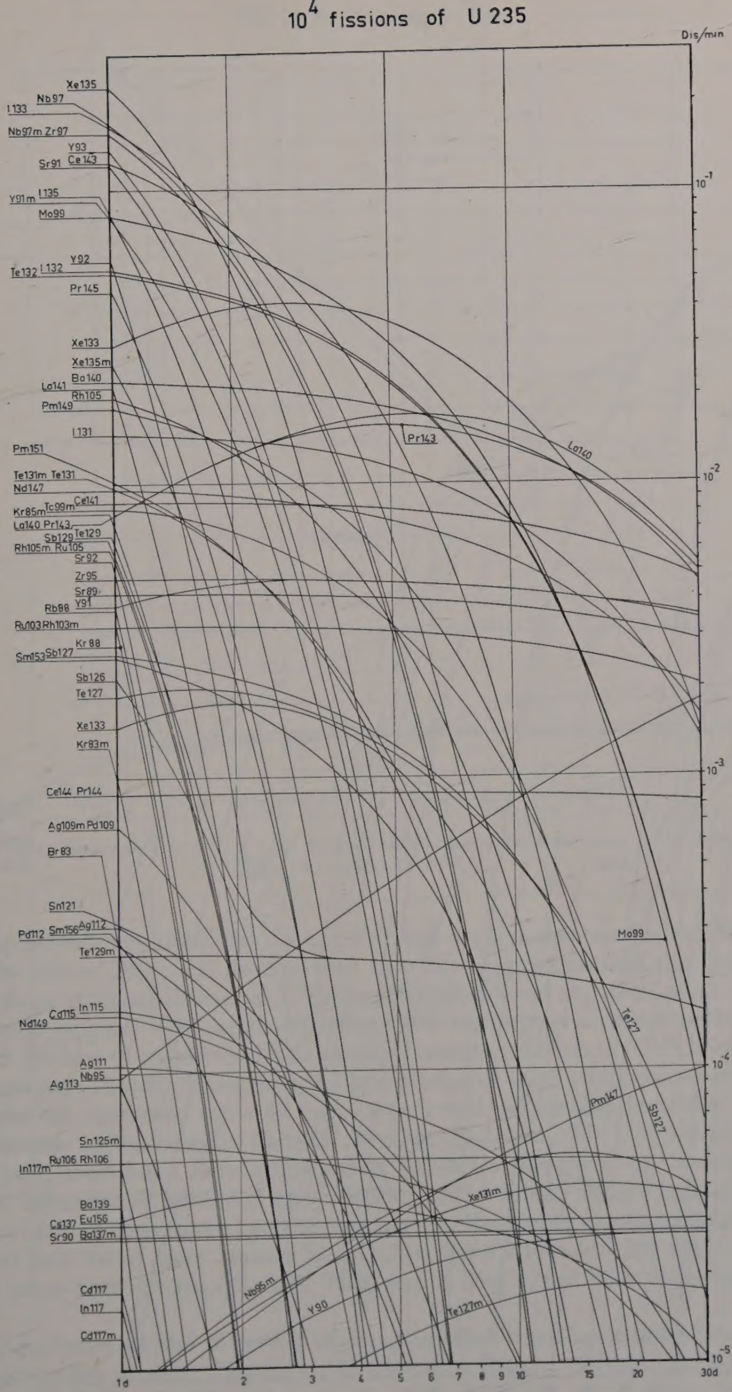
10^4 fissions of U 235
Dis/min
Xe135
Nb97
I133
Nb97m Zr97
Y93
Sr91 Ce143
Y91m I135
Mo99
Te132 I132 Y92
Pr145
Xe133
Xe135m
La141 Ba140
Rh105
Pm149
I131
Pm151
Te131m Te131
Nd147
Kr85m Tc99m Ce141
La140 Pr143
Sb129 Te129
Rh105m Ru105
Sr92
Zr95
Sr89
Rb88 Y91
Ru103 Rh103m
Sm153 Sb127 Kr88
Sb126
Te127
Xe133
Kr83m
Ce144 Pr144
Ag109m Pd109
Br83
Sn121
Pd112 Sm156 Ag112
Te129m
Nd149 Cd115 In115
Ag111
Ag113 Nb95
Sn125m
In117m Ru106 Rh106
Ba139
Cs137 Eu156
Sr90 Ba137m
Cd117
In117
Cd117m
Pr143
La140
Mo99
Te127
Pm147
Sb127
Xe131m
Nb95m
Y90
Te127m
10^-1
10^-2
10^-3
10^-4
10^-5
1d
2
3
4
5
6
7
8
9
10
15
20
30d

Fig. 2.

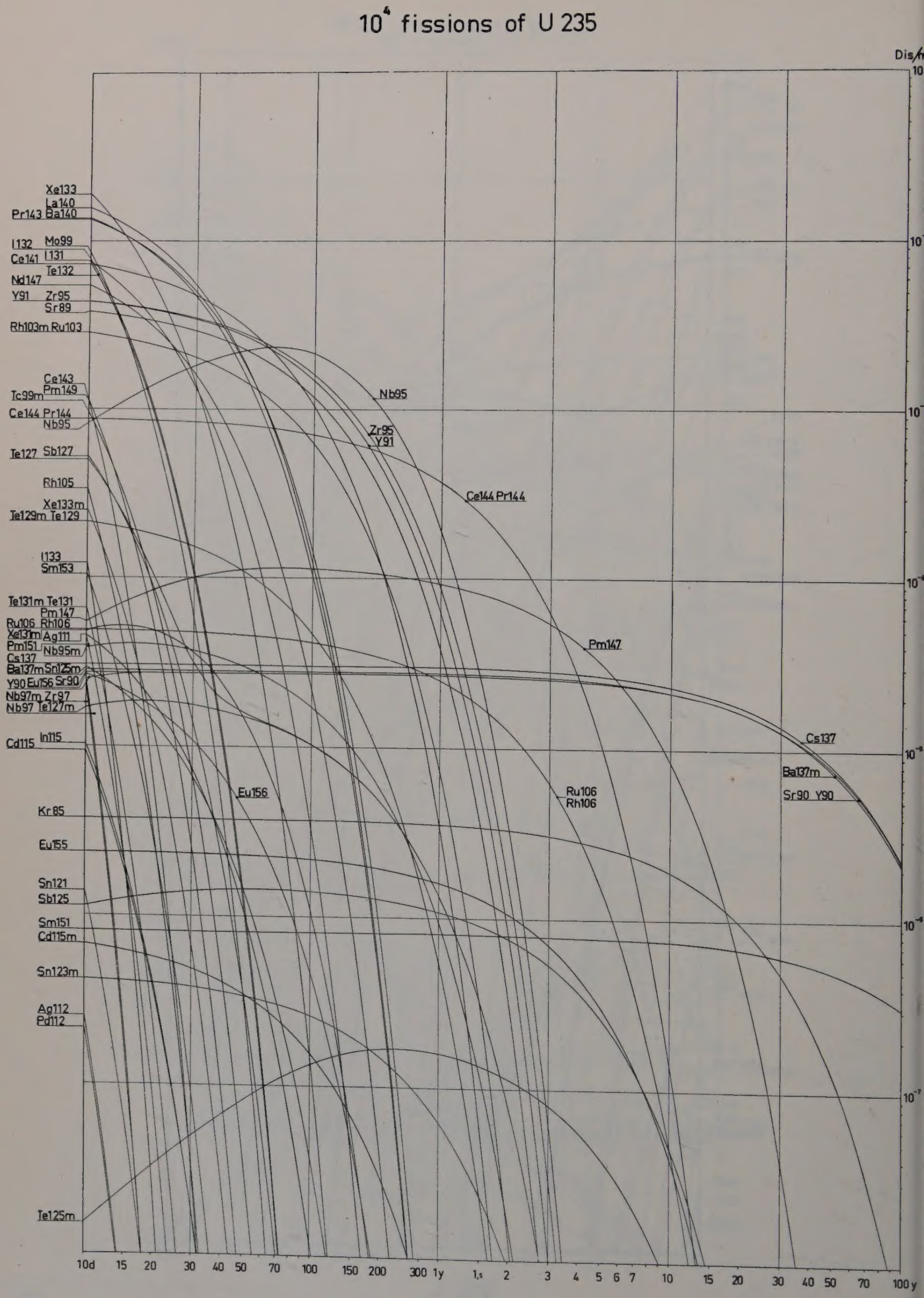
10^4 fissions of U 235
Dis/
10
10
10
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Xe133
La140
Pr143 Ba140
I132 Mo99
Ce141 I131
Te132
Nd147
Y91 Zr95
Sr89
Rh103m Ru103
Ce143
Tc99m Pm149
Ce144 Pr144
Nb95
Te127 Sb127
Rh105
Xe133m
Te129m Te129
I133
Sm153
Te131m Te131
Pm147
Ru106 Rh106
Xe131m Ag111
Pm151 Nb95m
Cs137
Ba137m Sn125m
Y90 Eu156 Sr90
Nb97m Zr97
Nb97 Te127m
Cd115 In115
Kr85
Eu155
Sn121
Sb125
Sm151
Cd115m
Sn123m
Ag112
Pd112
Te125m
Nb95
Zr95
Y91
Ce144 Pr144
Pm147
Cs137
Ba137m
Sr90 Y90
Eu156
Ru106
Rh106
10d
15
20
30
40
50
70
100
150
200
300
1y
1,5
2
3
4
5
6
7
10
15
20
30
40
50
70
100 y

Fig. 3.

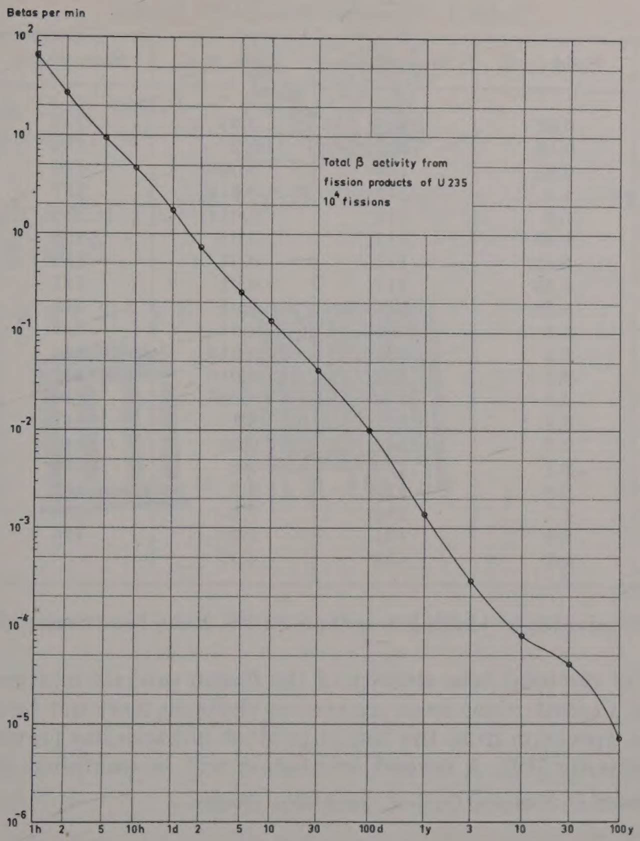

Fig. 4. In the interval 1 h–200 d the decay curve deviates less than 15 % from the formula $I = \text{const.} \cdot t^{-1.15}$.

these calculations are intended do not warrant an accuracy as high as that given in the results below. This fact implies that to a first approximation the fission product mixture from thermal fission of U^{235} may be considered representative of fallout of all different origins. This approximation will be improved upon in later articles.

Several studies of mixtures from thermal neutron fission of U^{235} have previously been published [16–19]. Since then the knowledge of both yield values and especially decay data has increased so as to make a renewed calculation justified. The present work concerns instantaneous thermal neutron fission of 10^{4} U^{235} nuclei. The chain yield values used have been collected in Table 1 to simplify any corrections of the results in accordance with e.g. new fission yield values. Where independant yield values are known, these have been accounted for. The decay characteristics (branching ratios and half lives) have mainly been taken from Blomeke [20] with single exceptions for more recent data [21, 22]. Thus e.g. a half life of 26.6 years has been used for Cs^{137}.

The decay rates of the different isotopes created have been calculated as a function of time after fission. The result is shown in Figs. 1–3. Isotopes with half lives

Table 1. Chain yields in U^{235} fission.

Mass chain	Yield in %	Mass chain	Yield in %	Mass chain	Yield in %
78	0.02	106	0.38	133	6.5
81	0.13	107	0.2	134	8.0
83	0.55	109	0.028	135	6.4
84	1.1	111	0.018	137	6.15
85	1.3	112	0.011	138	5.77
87	2.49	113	0.01	139	6.0
88	3.53	115	0.01	140	6.33
89	4.78	117	0.01	141	6.0
90	5.74	118	0.01	142	6.03
91	5.9	119	0.01	143	5.80
92	6.1	121	0.014	144	5.39
93	6.5	123	0.015	145	3.86
94	6.5	125	0.023	146	2.93
95	6.4	126	0.1	147	2.38
97	6.2	127	0.25	149	1.13
99	6.1	128	0.5	151	0.45
101	5.0	129	0.9	153	0.15
102	4.2	130	2.1	155	0.031
103	2.9	131	2.92	156	0.013
105	0.9	132	4.37		

shorter than 10 minutes or yields lower than 0.01% have been omitted in the calculations.

The decay of the total beta activity of the fission product mixture has been calculated, Fig. 4. Contributions from conversion electrons have not been included.

The gamma spectrum from the fission product mixture has previously been calculated preliminarily [19]. A revised calculation will be published shortly.

Research Institute of National Defence, Stockholm, Sweden.

REFERENCES

1. Hughes, D. J., Pile neutron research, Wesley Publ. Co. (1953).
2. Glendenin, L. E., and Steinberg, E. P., Intern. conf. on the peaceful uses of atomic energy, paper 614 (1955).
3. Petruska, J. A., Melaika, E. A., and Tomlinson, R. H., Can. J. Phys. *33*, 640 (1955).
4. Petruska, J. A., Thode, H. G., and Tomlinson, R. H., Can. J. Phys. *33*, 693 (1955).
5. Purkayastha, B. C., and Martin, G. R., Can J. Chem. *34*, 293 (1956).
6. Blades, A. T., Fleming, W. H., and Thode, H. G., Can. J. Chem. *34*, 201 (1956).
7. Reed, G. W., Phys. Rev. *98*, 1327 (1955).
8. Bartholomew, R. M., and Baerg, A. P., Can. J. Chem. *34*, 201 (1956).
9. Fleming, W. H., and Thode, H. G., Can J. Chem. *34*, 193 (1956).
10. Wiles, D. M., Petruska, J. A., and Tomlinson, R. H., Can. J. Chem. *34*, 227 (1956).
11. Peterson, S., CF-55-6-144 (1955).
12. Kukavadze, G. M., C. A. *50*, 6960 h (1956).
13. Spence, R. W., AECD-2625 (1949).
14. Howlett, J. *et al*, AERE T/R 589 (1950).
15. Engelkemeir, D. *et al.*, ANL-4927 (1952).
16. Way, K., and Wigner, E. P., Phys. Rev. *73*, 1318 (1948).
17. Hunter, H. F., and Ballou, N. E., Nucleonics *9*, No. 5 (1951).
18. Moteff, J., Nucleonics *13*, No. 5, 28 (1955).
19. Björnerstedt, R., Löw, K., and Ulvönäs, S., Res. Inst. Natl. Defence, Sweden, Res. Report (May 1955).
20. Blomeke, J. O., ORNL-1783 (1955).
21. Nuclear Level Schemes, TID-5300 (1955).
22. Nuclear Data Cards, Nat. Res. Counc. (1955–1956).

Tryckt den 17 december 1957

Uppsala 1957. Almqvist & Wiksells Boktryckeri AB